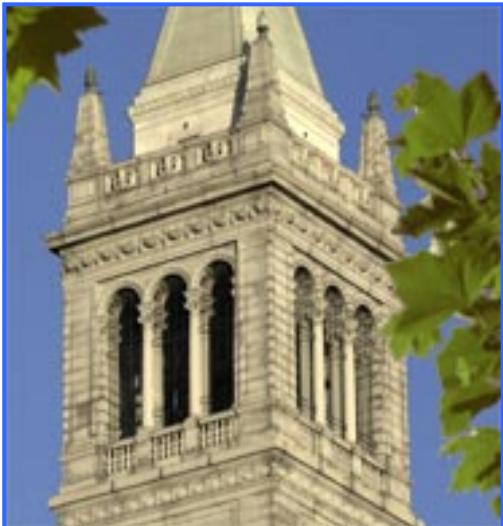


# XAS on the Rare-Earth Doped Magnetic Semiconductor a-GdSi



**Erik Helgren**

**ALS Users' Meeting  
Workshop on Advanced Magnetic Spectroscopy  
Wednesday 11<sup>th</sup> October 2006**

- University of California, Berkeley Department of Physics
- Lawrence Berkeley National Lab MSE Division, DOE



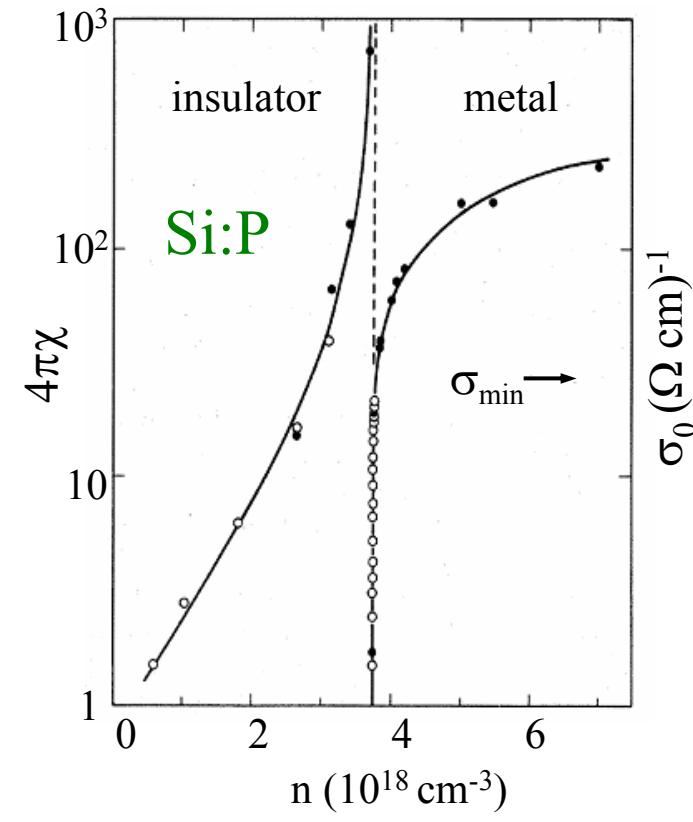
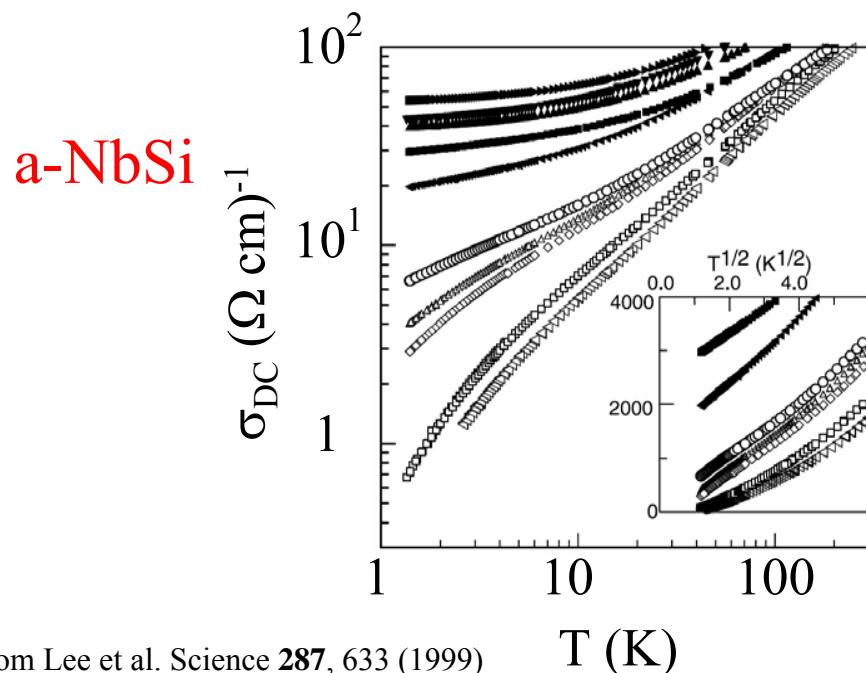


# Outline

- Metal Insulator Transition: Crystalline and Amorphous doped semiconductors
- a-GdSi: a magnetic semiconductor
- Physical properties of a-GdSi
- a-GdSi: initial XAS results and future Magnetic Spectroscopy work

# Metal Insulator Transition (MIT)

- Impurity band doping in **amorphous** or **crystalline** semiconductor: both examples of a disordered interacting system.
- MIT exists at T=0K as a function of doping.  
**Quantum Phase Transition (QPT)**
- DC conductivity goes to zero and dielectric constant diverges continuously at the transition.



**a-M<sub>x</sub>S<sub>1-x</sub>**  
xtal. Si:P

$$x_C \sim 0.1$$

$$x_C \sim 10^{-4}$$



# Magnetic Systems that show a MIT

Perovskite Manganite CMR oxides (e.g.  $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$ )

II–IV and III-V Mn-doped semiconductors (e.g.  $\text{Ga}_{1-x}\text{Mn}_x\text{P}$ )

as compared to

**Amorphous rare earth doped Silicon (a-Gd<sub>x</sub>Si<sub>1-x</sub>)**

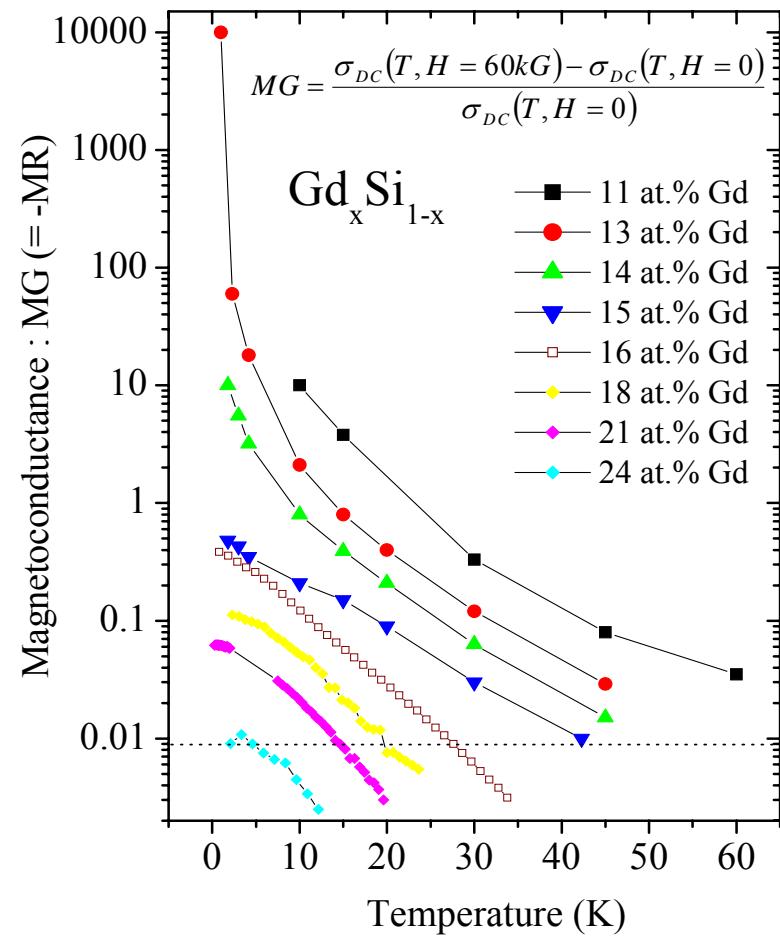
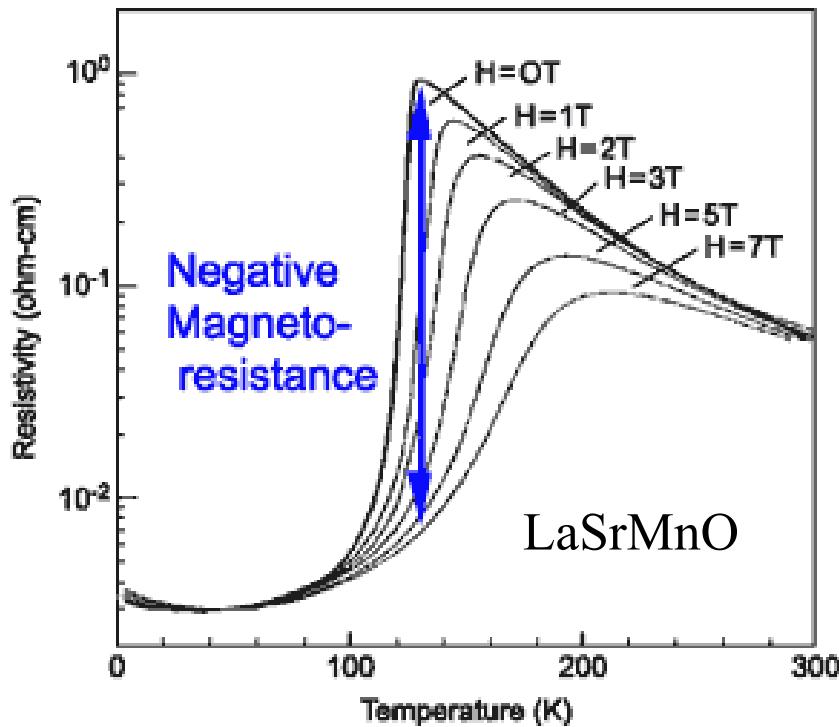
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- Correlated electron physics
- Strong coupling between electronic, magnetic and lattice degrees of freedom
- Role of magnetic moment – conduction electron interaction fundamental to understanding these systems

# Comparison with Amorphous Results

Similarities with crystalline magnetic semiconductors and CMR oxides:

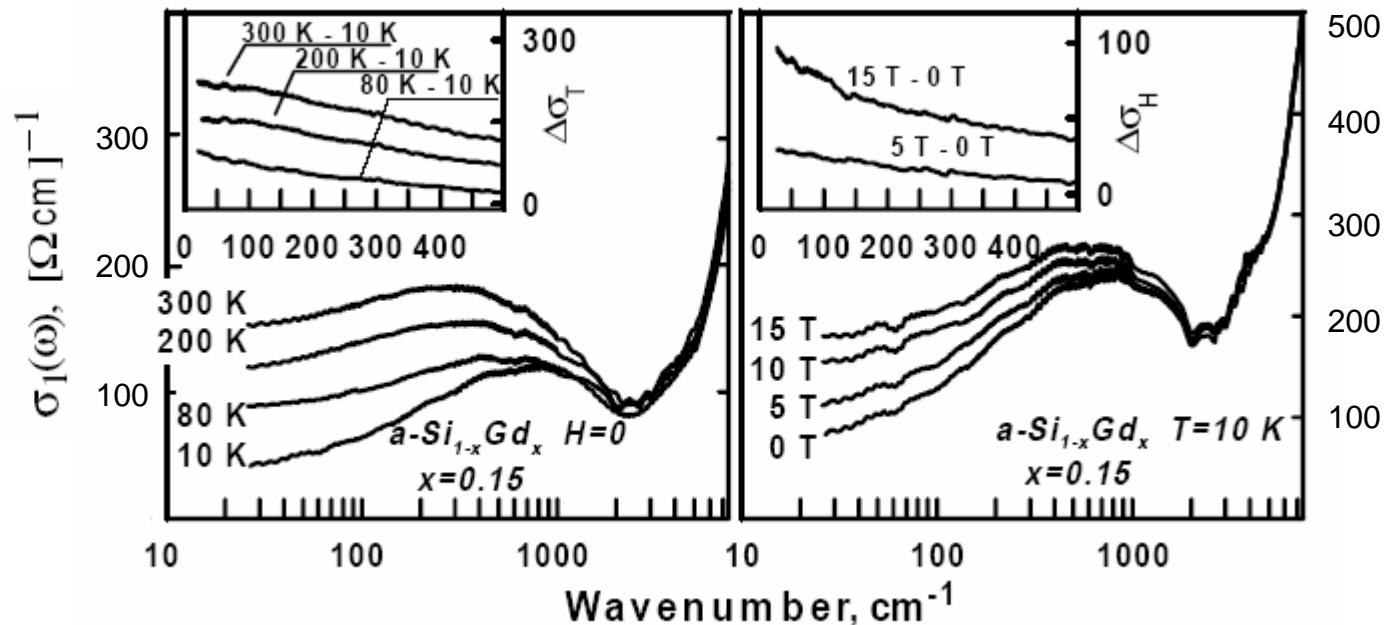
- Large negative magnetoresistance; Hellman et al. PRL **77**, 4652 (1996)



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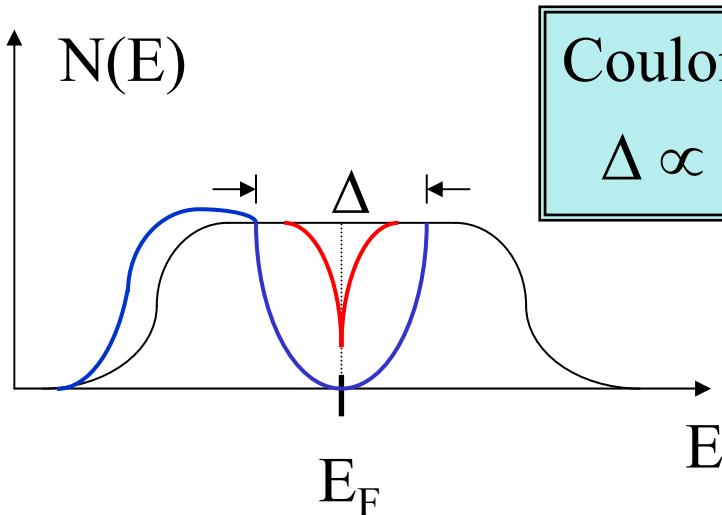
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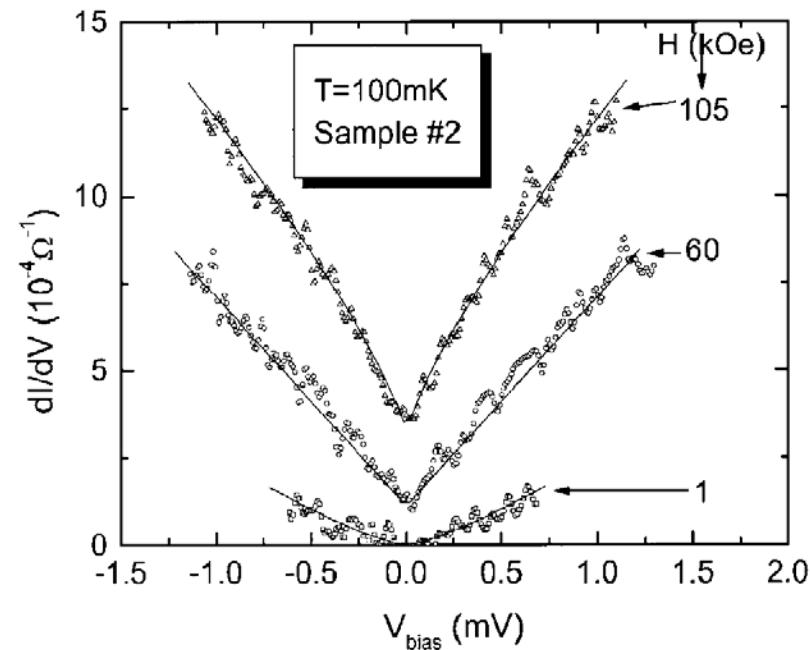
- Large negative magnetoresistance; Hellman et al. PRL **77**, 4652 (1996)
- Loss of spectral weight at low energy; Basov et al. Europhys. Lett. **57**, 240 (2002)
- A metal-insulator transition (MIT); Teizer et al. PRL **85**, 848 (2000)
- Shows aspects of both Anderson and Mott type transitions



**Coulomb Gap :**

$$\Delta \propto N_0^{1/2} / \epsilon_1^{3/2}$$

- Insulating :  $\delta N \sim |E - E_F|^2$
- Metallic :  $\delta N \sim |E - E_F|^{1/2}$





# Comparison with Amorphous Results

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Similarities with crystalline magnetic semiconductors and CMR oxides:

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Fundamental differences:

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- Naturally the system is amorphous and has a larger degree of disorder...
- The magnetic ground state is that of a *Spin Glass*
- DOS,  $E_F$ , **much greater** at dopant concentrations close to the MIT
- Extreme flexibility and ease of growth: *no clustering* even with high dopant concentrations!

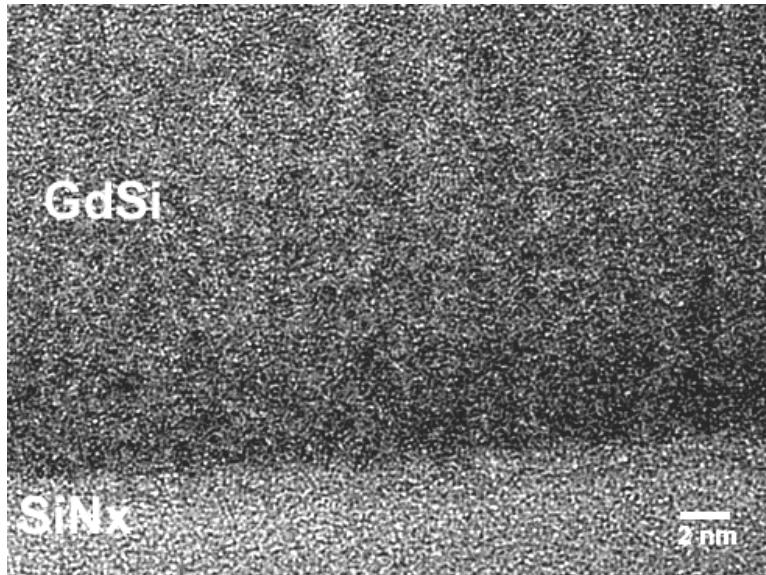


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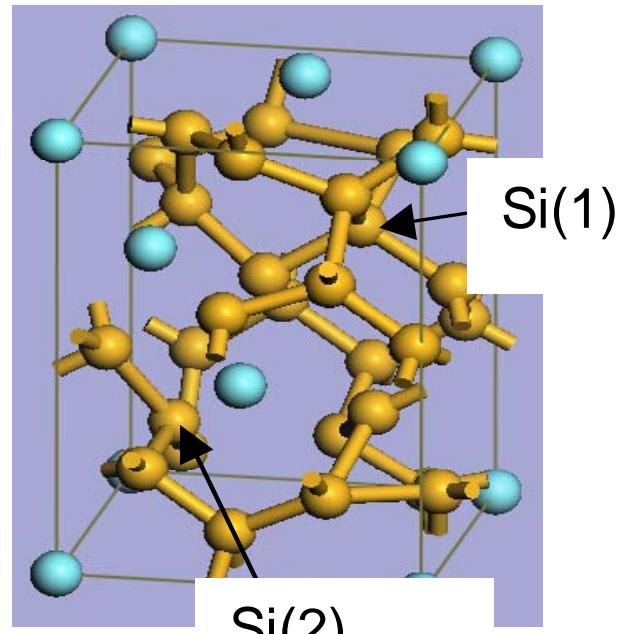
# Amorphous RE Semiconductors

HRXTEM: (D. Smith, ASU)



High resolution XTEM micrograph  
 $\text{Gd}_{0.18}\text{Si}_{0.82}/\text{SiN}_x$

FLAPW: (R. Wu, UCI)

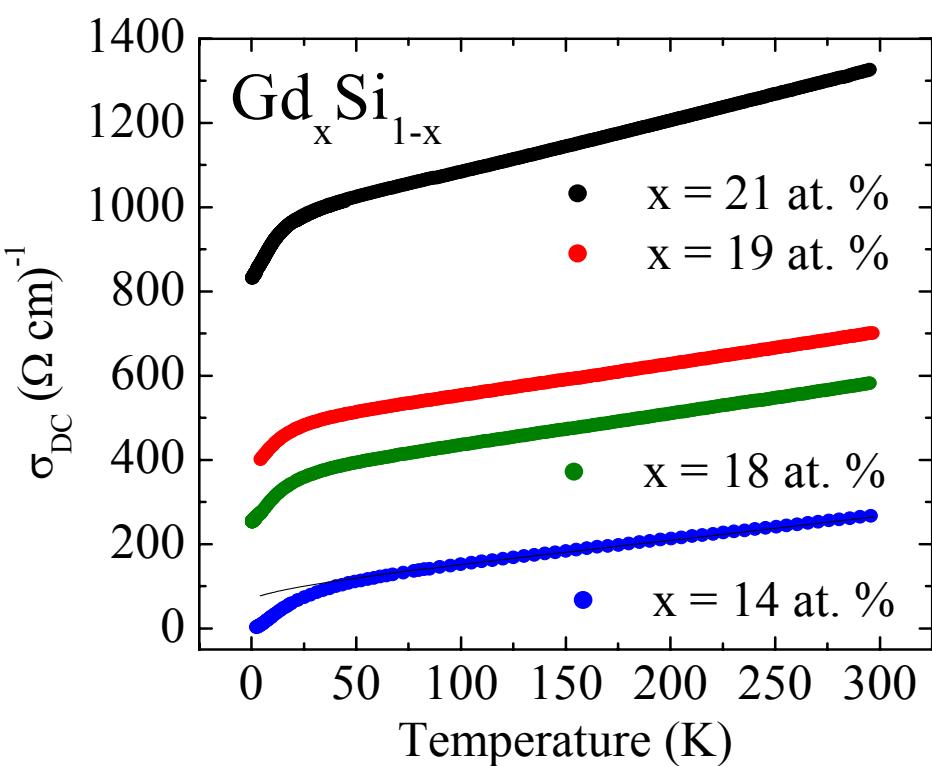


XAFS (J. Freeland & D. Haskel)  
•no evidence of Gd clustering

$\text{a-Gd}_x\text{Si}_{1-x}$

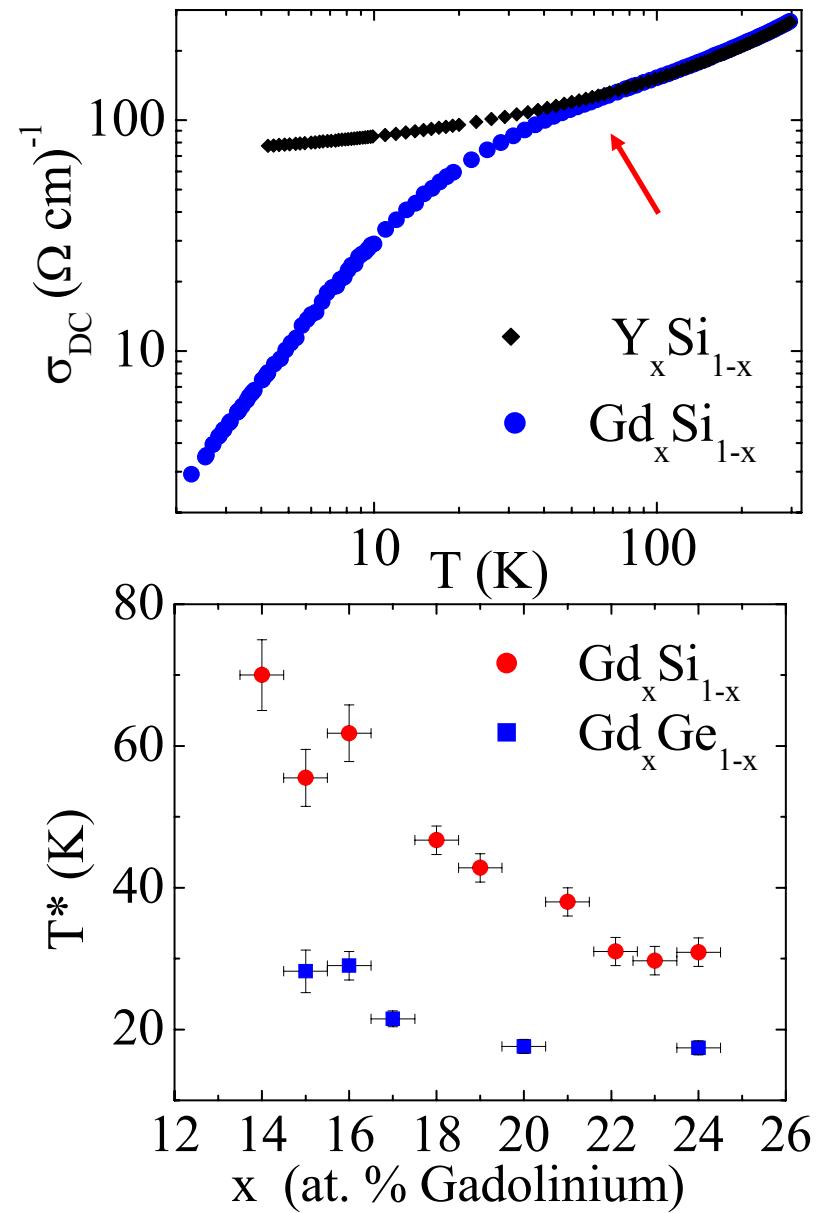
- Increased solubility limit
- Wide range:  $x = 0\text{--}24$  at. %

# DC Transport

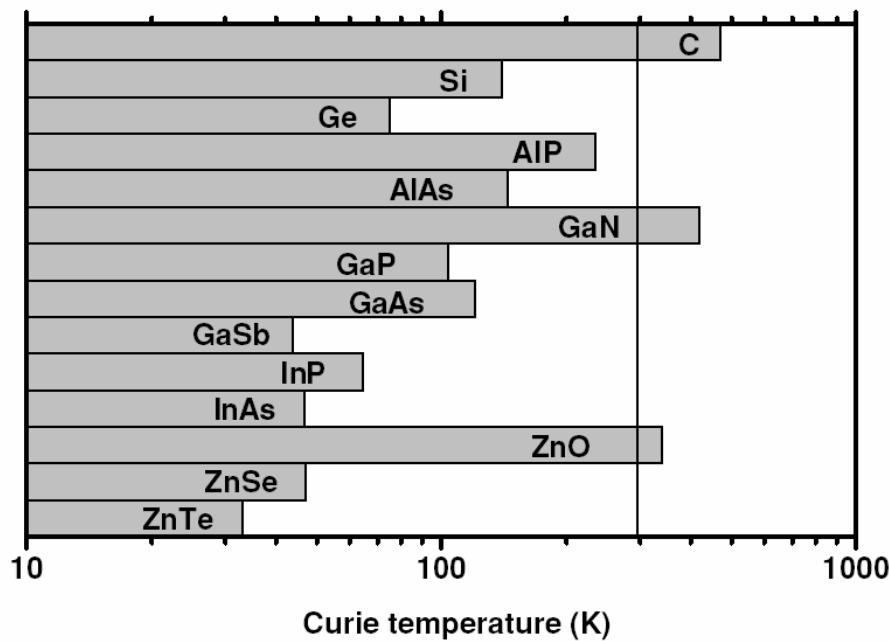


$$\sigma_{DC}(T) = \sigma_0 + A \cdot T^{1/2} + B \cdot T$$

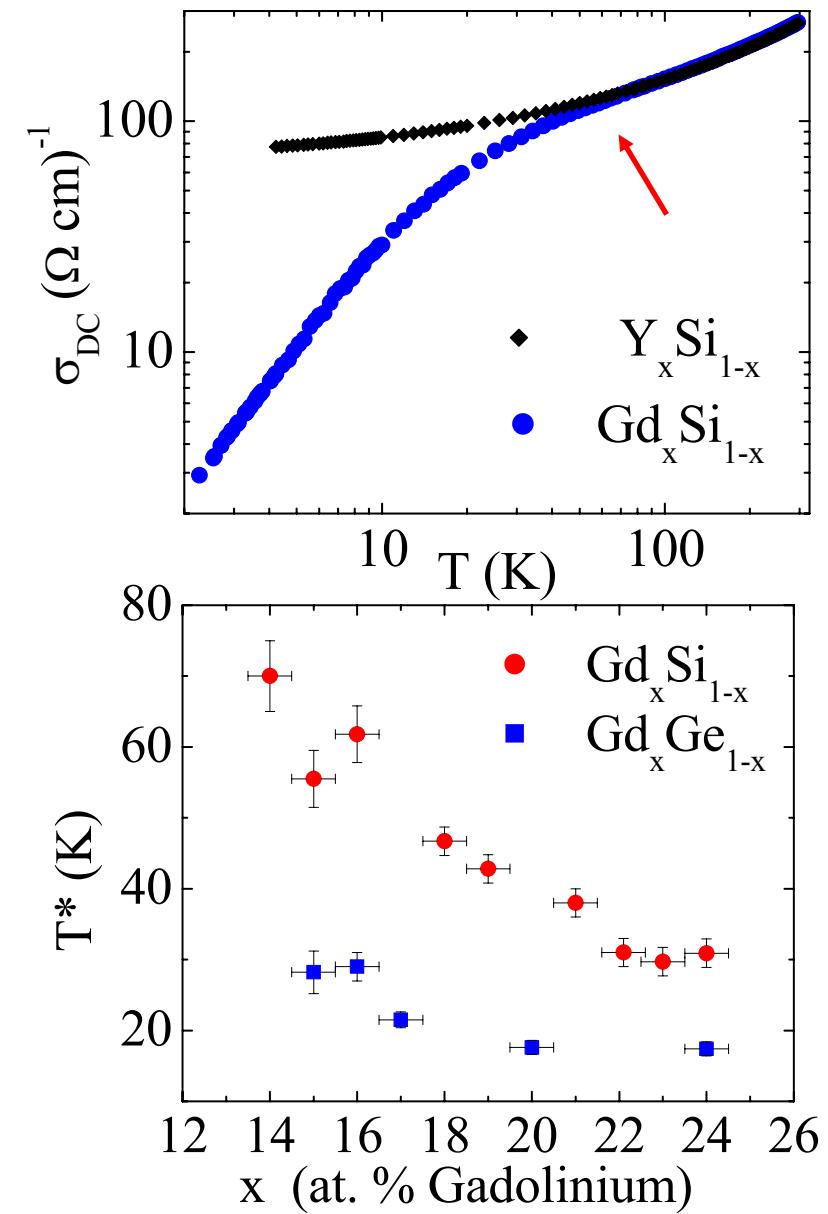
Weak localization & Altshuler-Aranov type interaction effects  
 Lee & Ramakrishnan RMP 57, 287 (1985)



# DC Transport



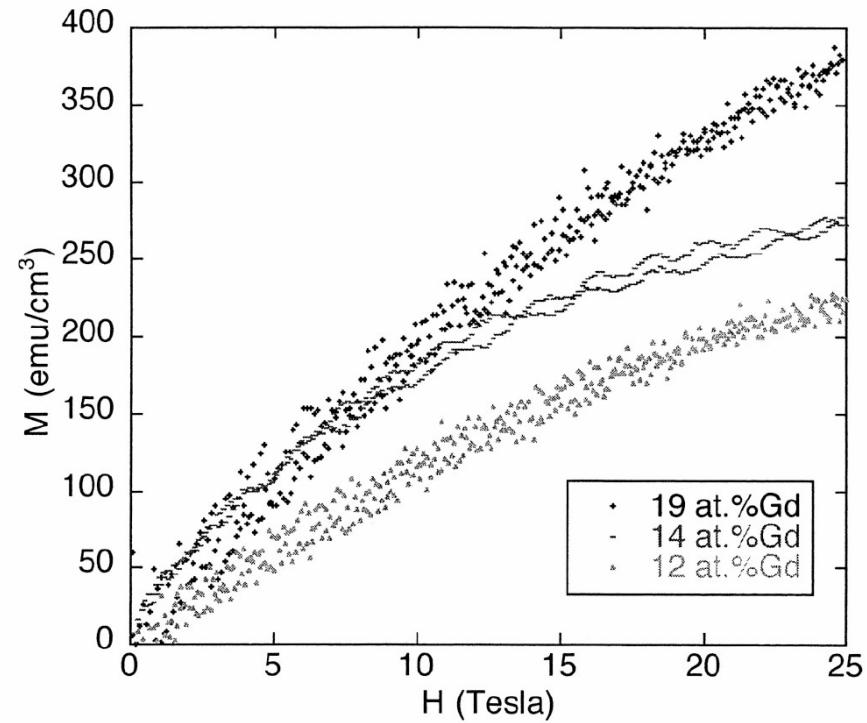
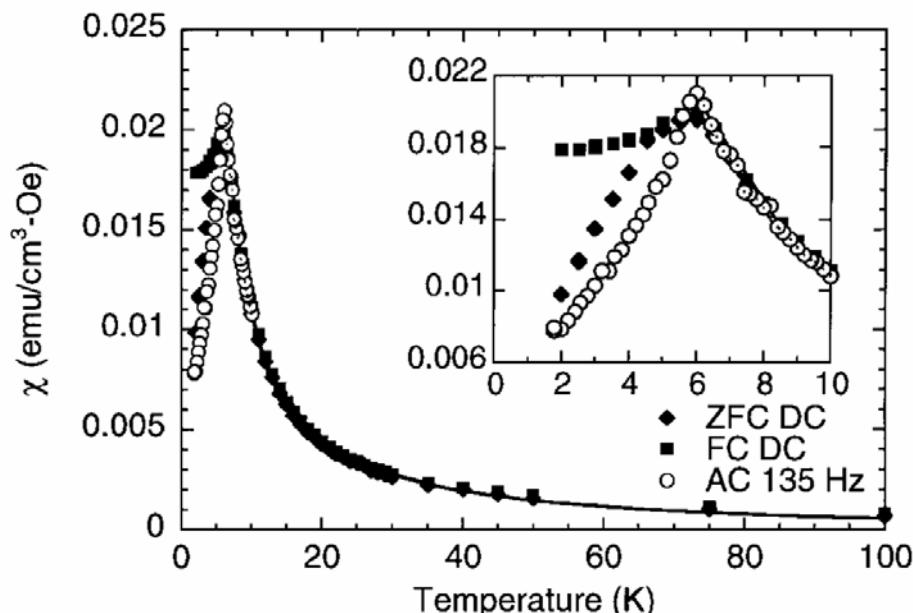
**Figure 8.** Computed values of the Curie temperature  $T_C$  for various p-type semiconductors containing 5% of Mn per cation (2.5% per atom) and  $3.5 \times 10^{20}$  holes per  $\text{cm}^3$  (after [27, 28]).



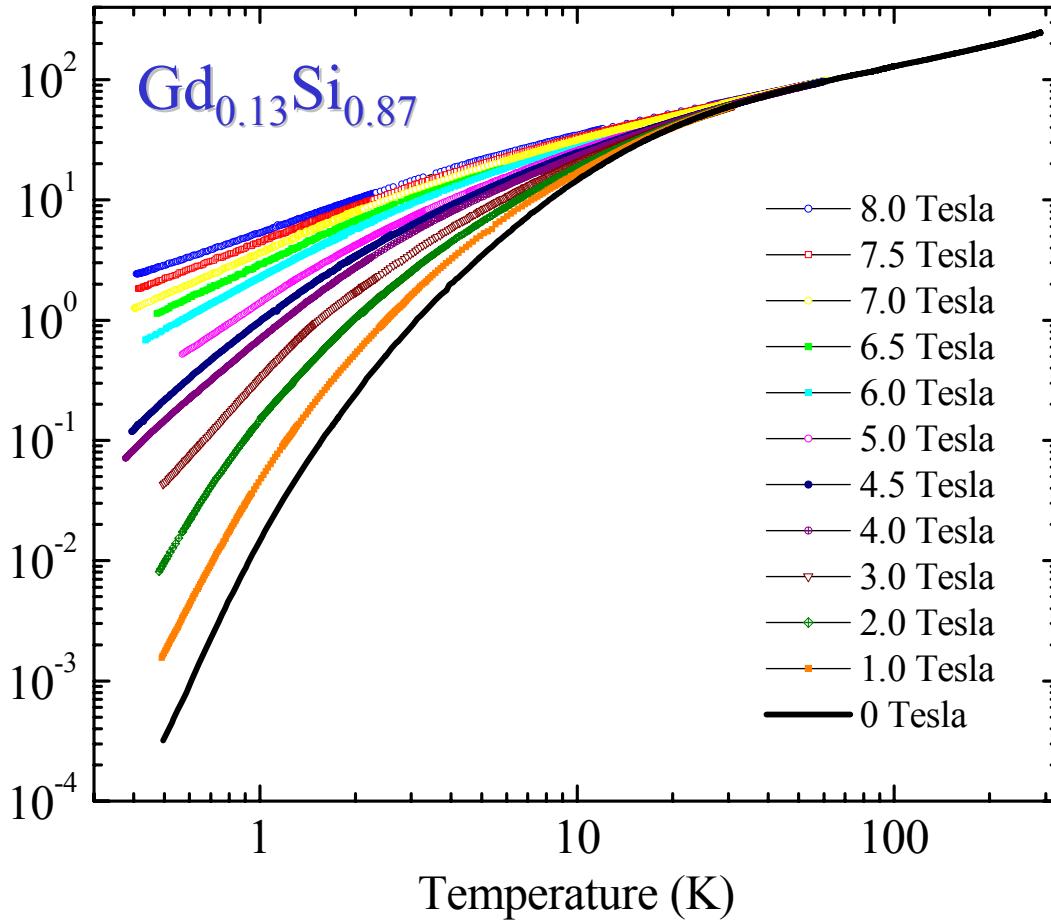
# Magnetic Properties

Magnetic ground state is a  
**Spin Glass**: frustrated FM  
and AFM interactions

$M_{\text{sat.}}$  not reached up to 25  
Tesla indicates extremely  
strong magnetic interactions



# Magnetoconductance

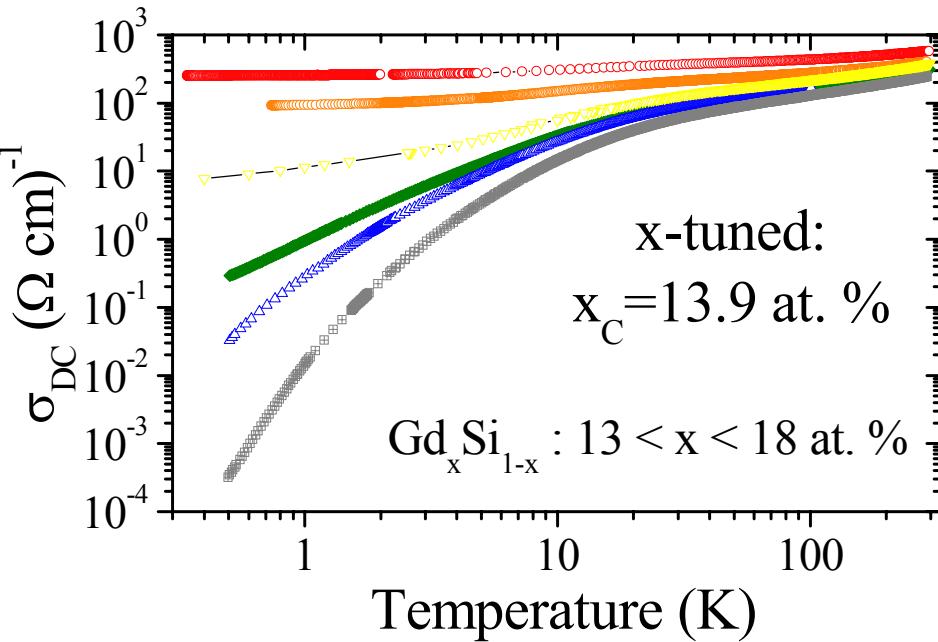
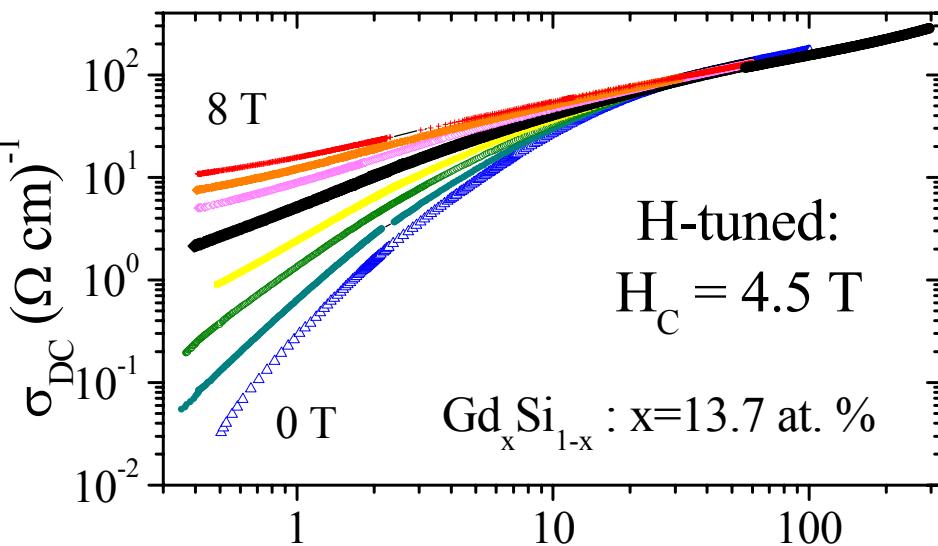


- $+MG = -MR$
- Altshuler-Aranov  $\Delta\sigma(H)$  predicted to be negative and max. 50-90%
- No theoretical model to describe this enormous delocalization transition

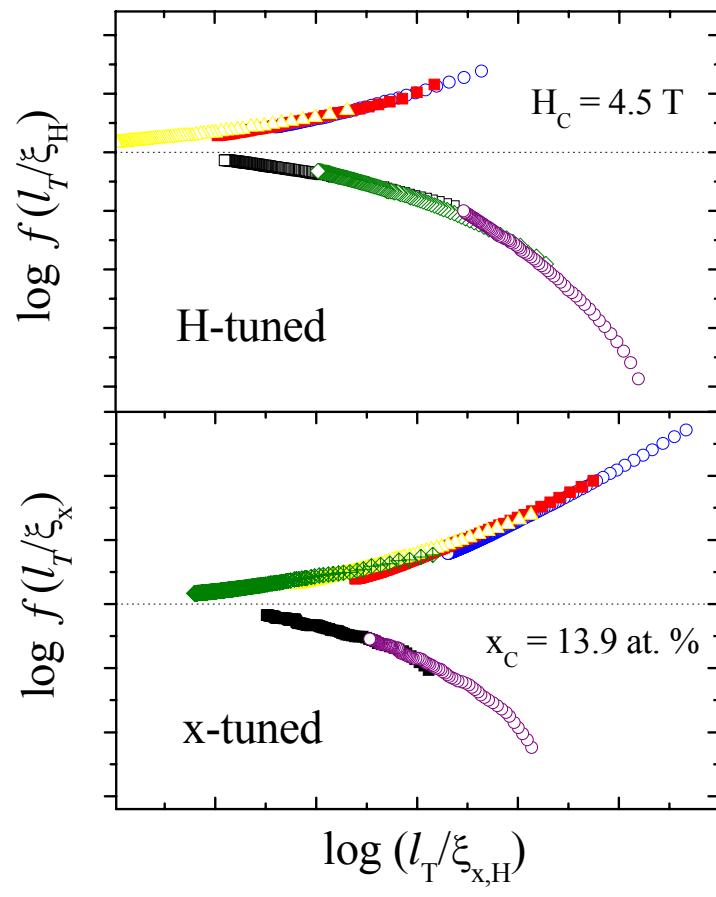
For Gd and Y doped a-Si,  $x_C=14$  at. %



# Quantum Phase Transition Scaling



- $x$  &  $H$  tuned data collapse
- Dynamic scaling exp.  $z = 2$
- Correlation length exp.  $\nu = 1$



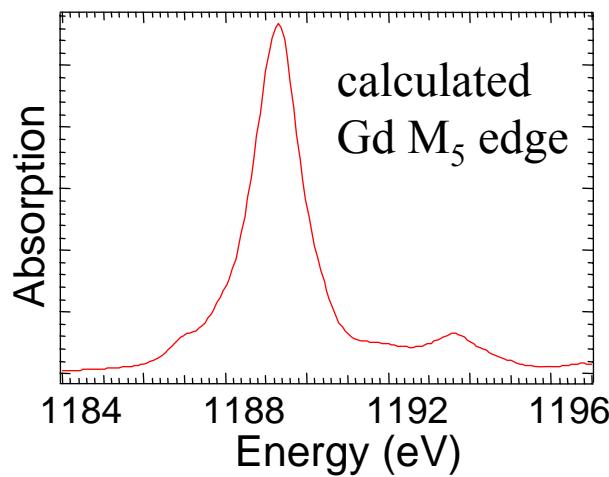
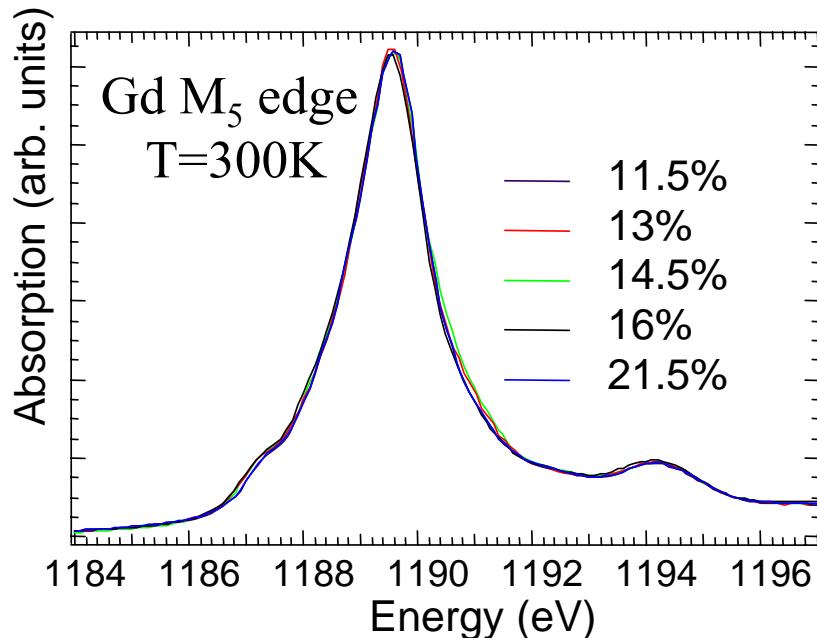


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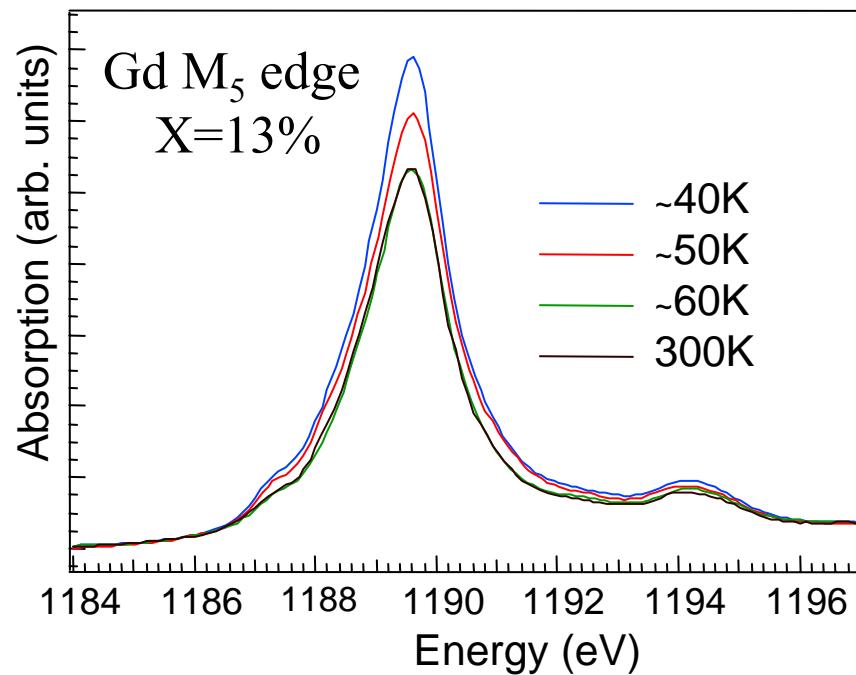
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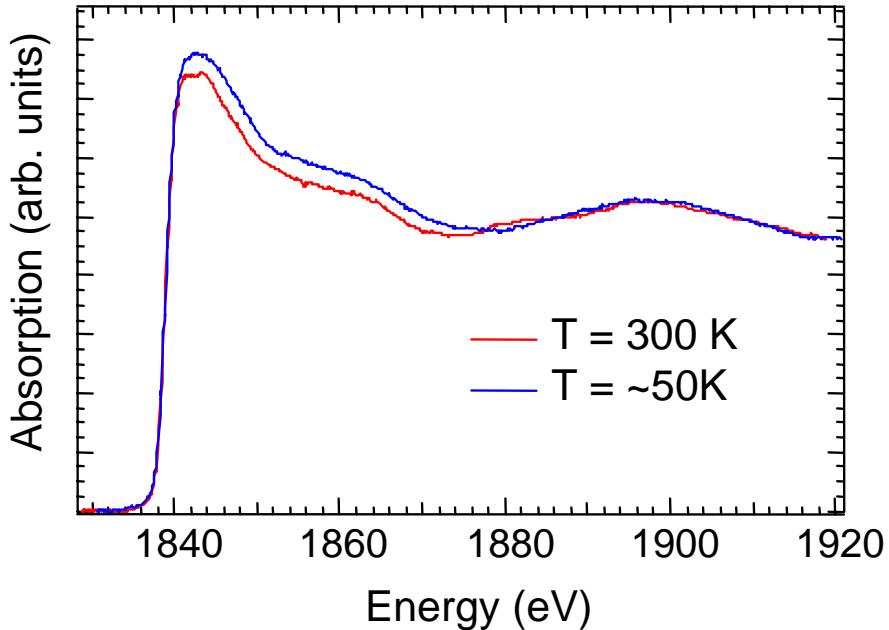
# XAS: Gd M<sub>5</sub> edge



- Indicates Gd in 3+ valence state
- Excellent agreement with calc. 3+
- Shape of spectra and location of the peaks don't change with T

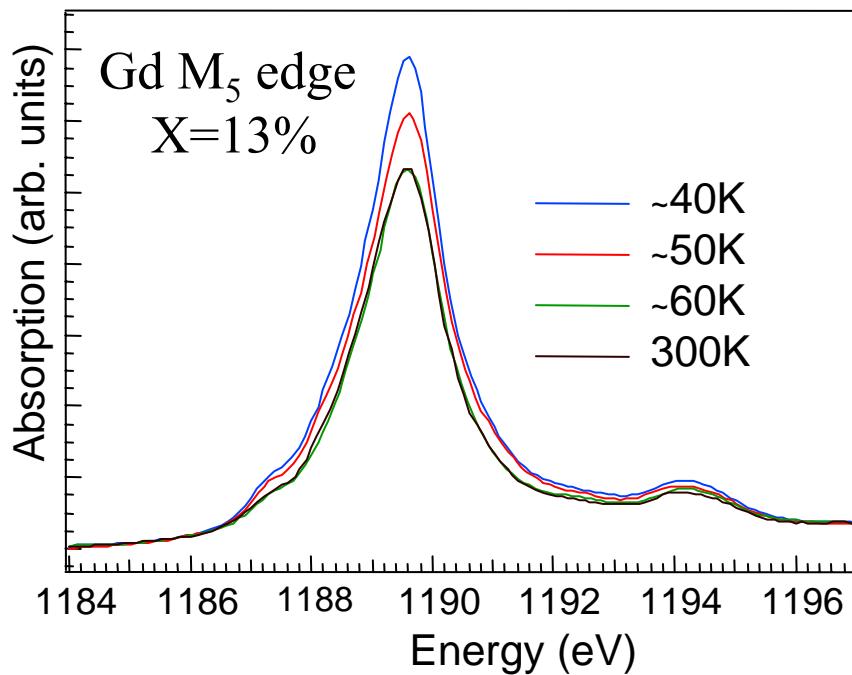


# XAS: Si K edge



Naturally further meas.  
to lower T and in field  
are desirable

- electronic structure modification
- $M_5$  occ. 3d  $\rightarrow$  unocc. 4f  
Also probes 3d  $\rightarrow$  unocc 6p (small)
- Si K occ. 1s  $\rightarrow$  unocc. 3p
- Conclude: Drop in unocc. Gd 6p DOS at low T





# Conclusions

Amorphous GdSi shows evidence of strong electronic correlations and strong magnetic moment-conduction electron interactions, similar to III-V systems and the CMR Oxides.

## Future Magnetic spectroscopy measurements:

Similar measurements on non-magnetic a-YSi : correlate Gd M<sub>4,5</sub>-edge background shift and the corresponding Si K-edge shift the with proper physics:

- i. Magnetic moment – conduction electron interaction?
- ii. Coulomb Gap : electronic correlation, DOS redistribution?

## Magnetic Field dependence of the M<sub>4,5</sub> and K edges

- i. XMCD for fully magnetized a-GdSi calculated to be 1/3 XAS intensity
- ii. Does even a small field dependence at 10K show delocalization effects, i.e. shift in background of M<sub>4,5</sub> disappears w/ increasing field = Spectral weight shift